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Results obtained with the CHARPAN Engineering Tool and prospects of the ion Mask Exposure Tool (iMET)

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ABSTRACT

Projection Mask-Less Patterning (PMLP) is based on many hundred thousands of ion beams working in parallel. A PMLP proof-of-concept tool has been realized as part of the European project CHARPAN (Charged Particle Nanotech) and has been presented at SPIE Photomask BACUS 2007. Using 10 keV protons, 16nm hp resolution has been demonstrated in non-CAR materials (HSQ) with 25μC/cm^2 exposure dose. The system is upgraded to a CHARPAN Engineering Tool (CHET) with a laser-interferometer controlled vacuum stage and a CMOS based programmable Aperture Plate System (APS) providing ca. 40,000 beams with < 20nm spot size. The engineering of an ion Mask Exposure Tool (iMET) for the 22nm hp mask node has been started; main iMET features are discussed.

1. Introduction

Mask fabrication for the 22nm hp node becomes extremely challenging as all RETs (Resolution Enhancement Techniques) have to be used with 193nm immersion lithography. E-beam mask writing are approaching throughput limits as shot sizes are becoming extremely small. The use of chemically amplified resists (CARs) is very unfavorable as the diffusion related blur contribution leads to a significantly reduced image contrast during development. Non-CAR materials require very high exposure doses making them unpractical for 50 keV electron beam use not only when using Gaussian but also Variable Shaped Beam (VSB) systems. PEC (Proximity Effect Correction) and measures to prevent fogging are becoming very complicated due to the increasingly complex mask patterns.

At BACUS 2007 the concept of PMLP (Projection Mask-Less Patterning) has been explained and first results as achieved with the Proof-of-Concept (POC) tool have been presented[1] as part of the European CHARPAN[2] project. PMLP uses a programmable aperture plate system (APS) in combination with 200x reduction optics to provide thousands of finely focused ion beams working in parallel on the substrate. The ability to expose non-CAR materials has found strong industrial interest for a proton multi-beam mask writer, called iMET (ion Mask Exposure Tool).

Resist-less PMLP is most suited for a variety of promising nanotechnology applications,[3] and is being explored in a number of European and Austrian projects, in particular in the field of nanophotonics,[4] nanobiotechnology[5] and for the fabrication of nanoimprint master templates.[6]

The present publication is concentrated on using proton multi-beam lithography for mask exposure, in particular on iMET.

2. CHARPAN Engineering Tool

With the CHARPAN POC tool exposures were done with 10 keV Hydrogen ions in 20 nm and 50 nm HSQ resist, achieving 16nm hp resolution within the 25 μm ∗ 25 μm exposure field of the system (Figure 1). There was excellent dose latitude of <1 nm change of line width with 10% increase of dose. The exposure dose was c. 25 μC/cm^2 for 20 nm as well as 50 nm resist thickness which is explained by the H$^+$ beam interaction with resist material: the exposure is achieved by the low energy (~eV) electrons emitted along the path of the Hydrogen ion transmitted through the resist material. The dose to clear large area patterns is 12.5 μC/cm^2 for Hydrogen ions whereas for 50 keV electrons this dose is as

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Editorial

Fab-Less Chrome Users

Wilhelm Maurer, Infineon Technologies

The promise & premise of the Fabless/Foundry setup has been to totally isolate the fabless product developer from all manufacturing issues, so that he (for simplicity, pls. read "he" in the following as "she or he") can concentrate all his efforts in designing the optimum product. He just delivers a DRC-clean GDSII file, and gets back at the agreed date the fully tested, functioning chips, maybe even packaged. As everywhere else, reality not always holds up to the promises of glossy presentation slides. The first item of concern has been money: Even for established technologies, discussions about the item called "ever-increasing mask cost" on the final bill of the foundry have been a reminder that things may not be as simple as all involved parties have meant them to be. This has become a particular issue when multiple cycles of learning, e.e., mask respins, are necessary.

Mask cost also becomes an issue at low volume chip manufacturing. Foundries have responded to this issue by providing so-called mask shuttles, where multiple product developers share a single reticle set. This saves money, but leaves the manufacturing schedule completely up to the foundry, which in many cases results in a delay in time to market. Some product developers with knowledge in lithography have started to discuss with their foundry the additional option to save mask cost by relaxing mask specifications. As mask specifications are part of the lithography error budget, relaxed mask quality drives tighter process control in the wafer fab. Knowledge of all aspects of masks surely is a valuable asset in such highly technical discussions.

As a reader of this newsletter, or as a participant at our BACUS Symposium, you are surely aware of all the complications generated by the fact that the design feature size has shrinked faster than the resolution of lithography tooling. Here, DfM (Design for Manufacturing) as a remedy by upstream communication from the foundry to design has started many years ago in form of recommended rules, and has evolved into some quite complex communications on how to incorporate the limits of manufacturing into design with the lowest impact on yield, performance and time lines. Recently, also the limitations of mask making limiting the capabilities of pattern transfer have become a topic in DfM. Product developers for the most advanced IC generations now know a thing or two about e.g. mask process correction or similar topics.

Some leading edge Fab-Less IC makers have even taken all the potential mask issues into their own hand, and send to their foundry not GDSII-data, but mask sets made according to the foundries' specifications.

So we see, that a new group of "paying" chrome users - defined as people who pay for masks in $$ and/or by restrictions to their business options - is emerging; maybe a better name for them is "Fab-Less Chrome Users". BACUS, our "Bay Area Chrome User Society", has always encouraged access & discussion to companies and individuals outside of the Bay Area, and has always been open topics beyond "mask-only" (see e.g. Peter Buck's analysis of last year's symposium papers in his editorial 2008/09). I believe Fab-Less Chrome Users should get even more attention by BACUS, to gain information critical to their business success, but also to the benefit our current BACUS members.

So what do you think? Which topics are in your point of view most important to "Fab-Less Chrome Users"? Maybe you have recently become one of those, and have a question on masks. I would like to start a discussion on "Fab-Less Chrome Users" in BACUS, their specific needs and interests. Your contributions will be forwarded for discussion by the BACUS Steering Committee, and you surely will hear back from me. Please contact me at wilhelm.maurer@infineon.com, I am looking forward to hearing from you.

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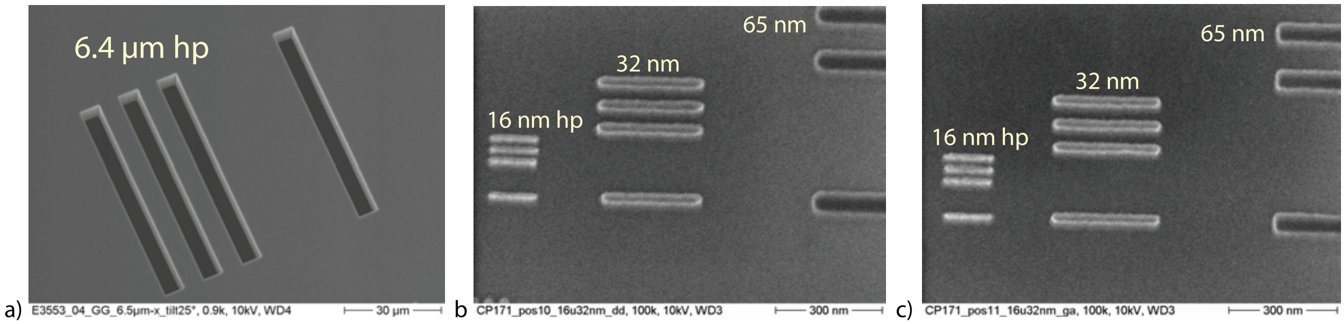

*Figure 1. CHARPAN POC tool exposure results as achieved with 10 keV H^+ ions in 20 nm HSQ resist when using a resolution template (a: detail with 6.4 µm opening) and 200x ion-optical reduction at center (b) and corner (c) of the 25 µm * 25 µm exposure field with an exposure dose of 24 µC/cm^2.*

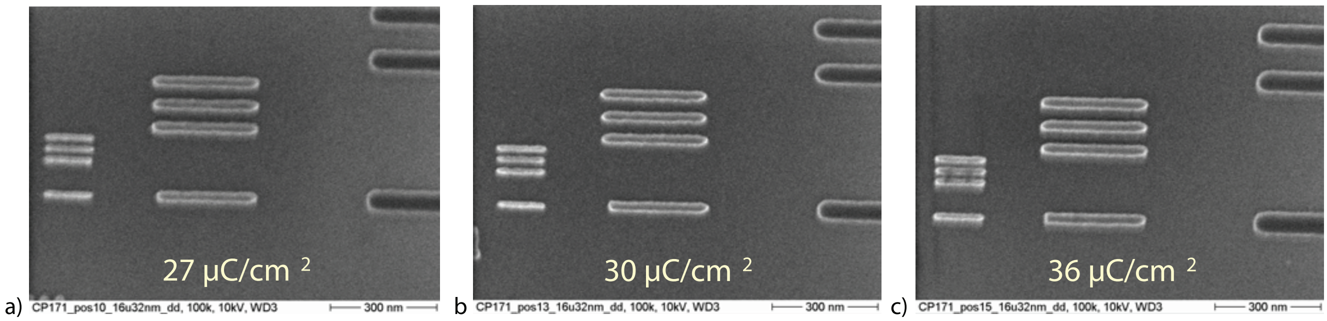

Figure 2. Exposure latitude for Figure 1c (corner of exposure field).

high as 600 µC/cm^2 for the same resist (Fox-12) and development conditions.[7] The enhancement factor of ~ 50 allows the use of non chemically amplified resist (non-CAR) materials when using proton multi-beams. From evaluations of line width vs. exposure dose the 10 keV H^+ ion beam intensity profile was evaluated which can be fitted with an error function curve of 6.5 nm Gaussian sigma, equivalent to 15 nm FWHM blur.

The ion-optical column with 200x reduction as realized for the POC tool will be incorporated into the CHARPAN Engineering Tool (CHET) for which a new target chamber and improved column interface has been fabricated. Full CHET performance including an integrated laser-interferometer controlled vacuum stage is expected in Q1 2009. Furthermore, a precursor gas injection system will be positioned between ion-optical column and substrate (Figure 4a) providing possibilities for resist-less high aspect ratio etching or deposition (Figure 4b).

The CHARPAN Engineering Tool will use a programmable Aperture Plate System (APS) with c. 43,000 beams. The Blanking Plate with integrated CMOS electronics has been realized by Fraunhofer ISIT (Figure 5). Full functioning according to specifications has been achieved as verified with the help of an APS test bench for 99.96 % of the 43,008 deflection electrodes and corresponding beamlets. The Si Aperture Plate has been fabricated by the Institute for Microelectronics Stuttgart (ims chips) where the integration of CMOS-APS units has been pre-tested with ± 0.5 µm overlay between Aperture and Blanking Plates.[8] The first Aperture Plates will have apertures with 3.75 µm opening width, providing ion beamlets with < 20 nm shot size. The fabrication of Aperture Plates with 2.5 µm opening width is planned then providing 12.5 nm shot size. Both Aperture Plates will fit to the same Blanking Plate with 30 µm x 30 µm cell size.

The CHARPAN Engineering Tool will be operated with ion beam energies up to 20 keV at the substrate. At 10 keV a resolution of 16nm hp has been achieved with Hydrogen ions in excellent comparison with the ion optical simulations. The same resolution has been achieved with 10 keV Argon ions when operating the column at low currents through the ionoptics. When increasing the energy to 20 keV and using Hydrogen ions a resolution of < 10 nm hp is expected (Figure 6). When using 20 keV Argon ions a resolution of 16 nm hp is predicted for 1 nA total current through the column. Compared to FIB systems which deliver a few pA current (Ga^+) at < 20 nm resolution a productivity enhancement by two to three orders of magnitude is predicted to be achievable with the CHARPAN Engineering Tool.

The CHARPAN Engineering Tool can be used with advantage for early mask development and, with respect to the ion Mask Exposure Tool (iMET), for establishing non-CAR processing.

3. iMET – Ion Mask Exposure Tool

Based on substantial industrial interest, the engineering of an ion Mask Exposure Tool (iMET) has been started for the 22 nm hp mask node, with the possibility of extendibility to 16nm hp and lower mask nodes. The preliminary iMET specifications for the 22nm hp mask node are listed in Table 1.

An energy of 50 keV is chosen for the Hydrogen ions at the mask substrate in order to achieve very low forward scattering even when exposing 100 nm resist. Detailed ray tracing has been done with

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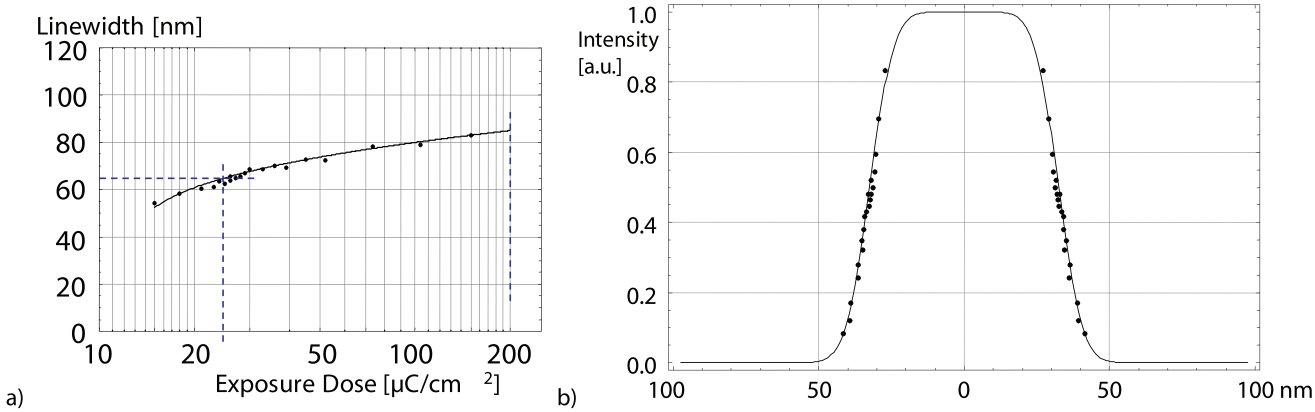

Figure 3. Linewidth vs. exposure dose for a 65 nm single line (a) and deduced 10 keV H+ ion beam intensity profile, fitted with an error function with Gaussian sigma = 6.5nm, corresponding to 15 nm FWHM blur.

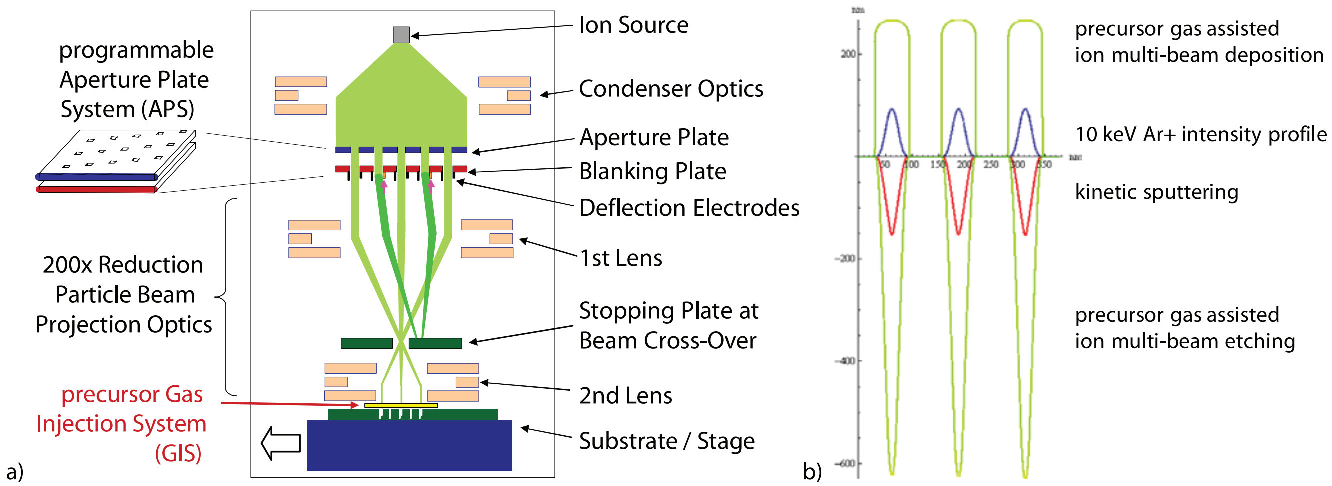

Figure 4. CHARPAN Engineering Tool with precursor Gas Injection System (GIS) and IonShaper™ simulated performance.

the result that for 90 nA total current of the 50 keV H^+ ion beamlets through the iMET ion-optics the FWHM blur is equal to 35 nm. As there are up to 262 thousand beams the beamlet current is ~ 0.35 pA and the current density of the 40 nm shots at the mask substrate is ~ 20 mA/cm^2.

There are efficient means to achieve adequate performance for the 22nm hp mask node when using 40 nm shot size with 20 nm physical grid. Each shot is exposed with 32 (5 bit) gray levels achieving 20/32 = 0.625 nm address grid. An even smaller address grid of ca. 0.16 nm is feasible implementing 10 nm physical grid and 6 bit gray levels for the shot exposures.

4. iMET Thoughput Potential

The iMET mask exposure time is equal to [(mask area) ∗ (D ∗ pd [%]/100)] / I, with D = resist exposure dose, pd = pattern density and I = total current of the ion beamlets through the ion-optics.

With I = 90 nA, D = 25 µC/cm2 and pd = 100% the iMET writing time is about 10 hours for a mask area of 104 mm ∗ 128 mm (corresponding to a 26 mm ∗ 32 mm die field). Mask exposure is done in stripes with constant stage velocity of 5 mm/s.

There is the possibility to allow “permanently on” and “permanently off” APS defects. When knowing the location of these defects the exposure can be modified to obtain tolerable errors. Without knowing the location of APS defects a redundancy mode can be chosen needing some writing overhead. For a redundancy level of n = 4 this overhead is c. 1.1 hours.

The iMET throughput including overheads for stage return, registration and mask substrate change times is predicted to be c. 14 hours per mask.

The most stringent 22 nm hp mask node specifications with respect to pattern placement can only be fulfilled with an adequate laser-interferometer controlled stage integrated into a well designed platform housing the iMET ion-optical column. Technical solution possibilities for achieving 2 nm (3s) pattern placement over the full 6” mask blank area have been established.

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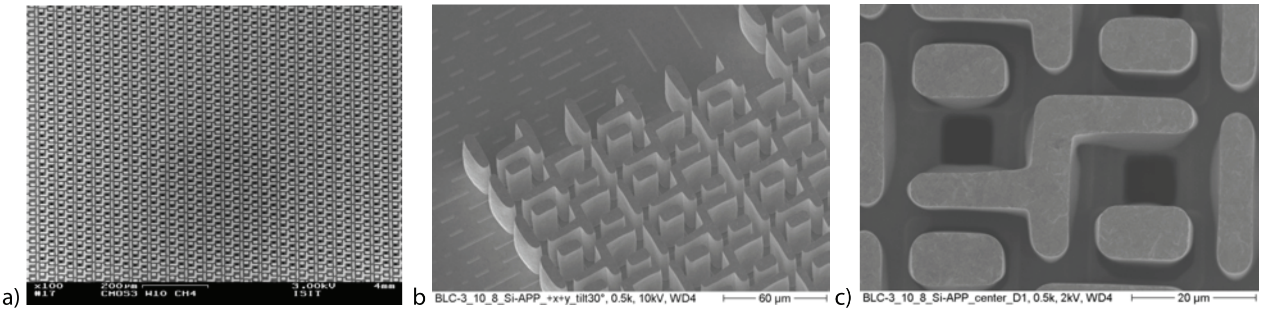

Figure 5. Blanking Plate Chip (BLC) with integrated CMOS electronics and UV-LIGA electroplated ground and deflection electrodes of 32 µm height as fabricated by the Fraunhofer Institute for Silicon Technology (Itzehoe, Germany); a) detail of 5.76 mm ∗ 6.72 mm field with 43,008 cells, b) side view of electroplated ground and deflection electrodes, c) top view showing 7 µm ∗ 7 µm apertures through the 30 µm Si plate of the BLC. The BLC cell size is 30 µm ∗ 30 µm.

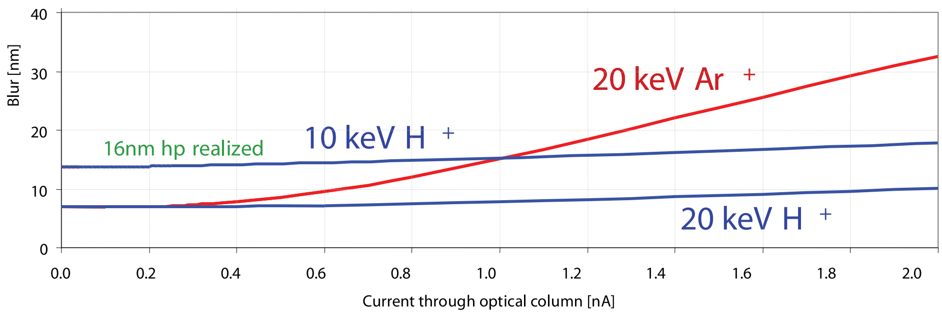

Figure 6. Ion-optical calculations of the resolution capability of CHET for 10 and 20 keV energy of H^+ and A^+ ions.

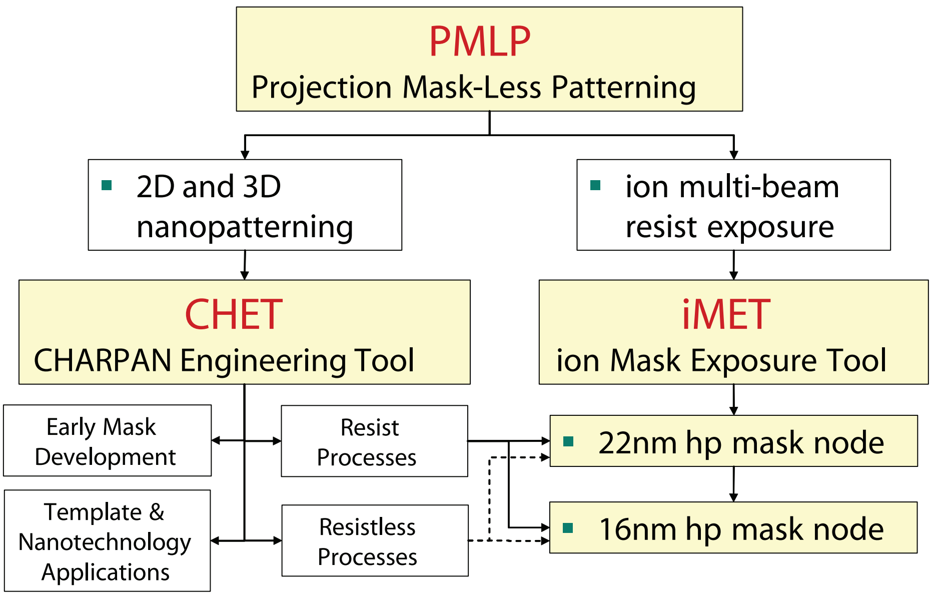

Figure 7. PMLP Tool Development a) CHET – CHARPAN Engineering Tool b) iMET – ion Mask Exposure Tool.

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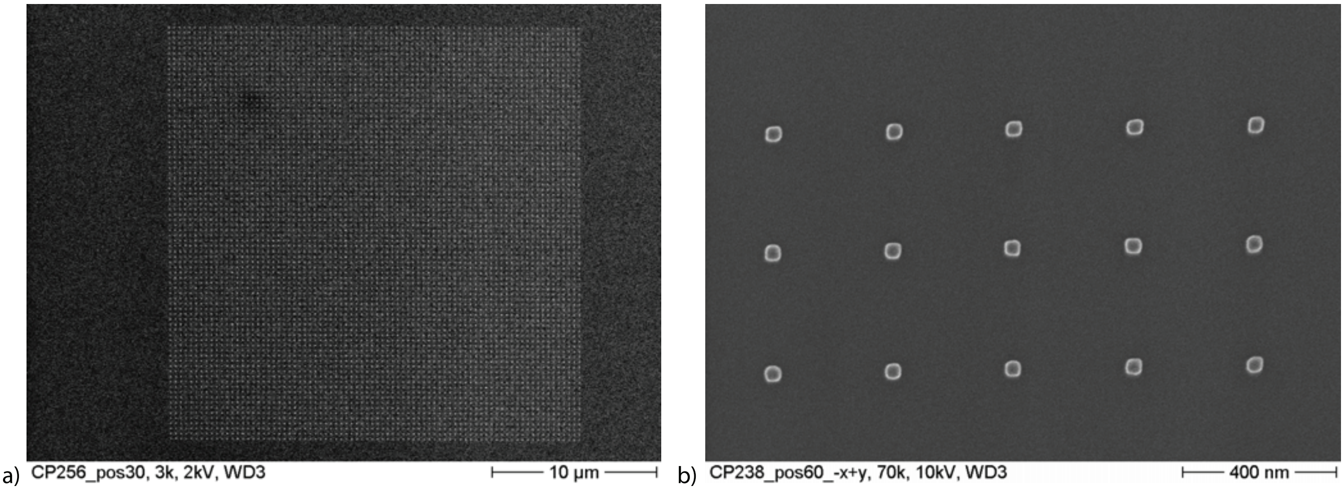

Figure 8. CHARPAN Tool exposure of 6400 dots of 40nm spot size as obtained with 10 keV H^+ ion with 25 µC/cm^2 exposure dose in 50 nm HSQ resist on a Si wafer: a) 6400 dots within the 5120 µm x 5120 µm exposure field, b) 40 nm spots at center; c) 40nm spots at corner of the exposure field. The dot periodicity is 320 nm.

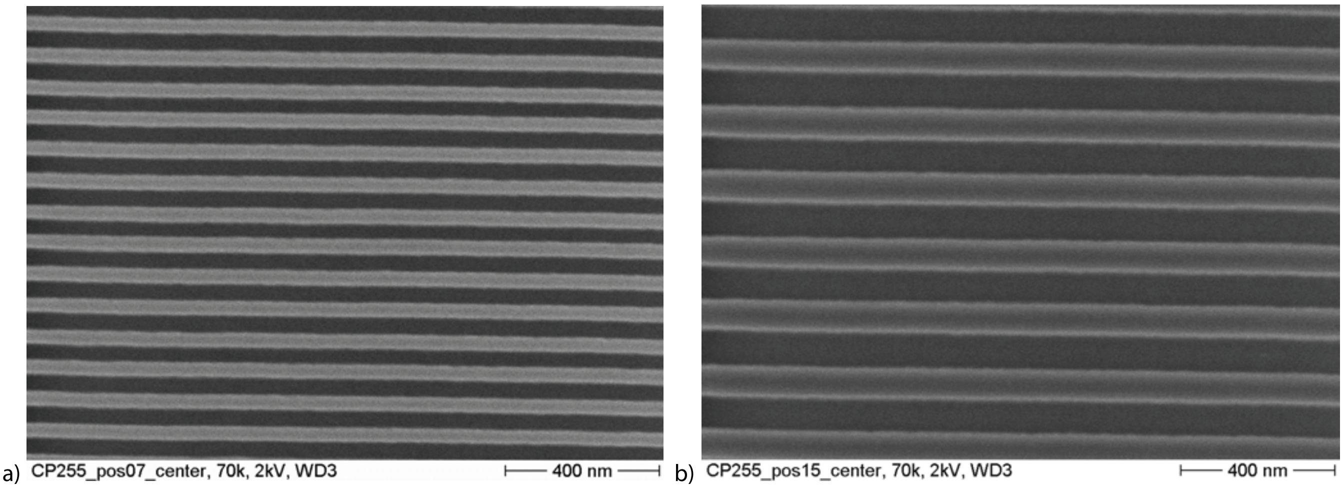

Figure 9. CHARPAN Tool exposure of 40 nm hp (a) and 80 nm hp lines (b) in 50 nm HSQ resist with 10 keV H^+ ions using 40 nm spot size and gray scaling techniques.

5. Anticipated iMET Performance as Verified with the CHARPAN Tool

The iMET-22nmhp exposure conditions were tested with the existing CHARPAN tool, inserting a template with 6400 apertures of 8 µm $*$ 8 µm opening size within a 5 mm $*$ 5 mm field providing 40nm spots within the 25 µm $*$ 25 µm exposure field (Figure 8a, enhanced views of the 40 nm spot are shown in Figure 8b at one corner of the field).

Using these dots and gray scaling exposure techniques 40 nm hp and 80 nm hp lines have been realized (Figure 9). As the dispersed ion beam intensity distribution. From these measurable values the line edge roughness for the exposed lines can be evaluated resulting in LER values of < 2nm (3σ).

6. Conclusions

Based on experimental results as obtained with the CHARPAN Tool the anticipated performance of the proposed ion Mask Exposure Tool (iMET) for the 22 nm hp mask node has been studied. iMET engineering is in full progress in cooperation with selected partners. The iMET offers a viable solution for leading-edge complex masks as needed for high-volume 22nm hp lithography with extension possibilities for the 16 nm hp node and below.

7. Acknowledgment

This work was supported by the European Commission through funding of the integrated project CHARPAN (Charged Particle Nanotech; www.charpan.com). Gray scale exposure data preparation was done with the “Layout Beamer“ software from GenISys.

Table 1. Preliminary Specifications of the ion Mask Exposure Tool (iMET) for the 22nm hp mask node.

Ion Species / Beam Energy	H^+ / 50 keV
Number of Apertures / Beams	262,144 (512*512)
Ion-Optical Reduction	200x
Exposure Spot Size	40 nm
Physical Exposure Grid	20 nm (option: 10 nm)
Address Grid	0.625 nm (option: 0.16 nm)
Current through column (max.)	90 nA
Current per beam	0.35 pA
Exposure Stripe Width	80 µm
Stage velocity (max. writing mode)	5 mm/s
Data Rate at Substrate	5 Gbit/s (option: 14 Gbit/s)
Troughput (incl. overheads)	14 hours per mask

8. References

[1] Elmar Platzgummer, Hans Loeschner, and Gerhard Gross: “Projection Mask-Less Patterning (PMLP) for the fabrication of leading-edge complex masks and nano-imprint templates”, **Proc. SPIE Vol. 6730** (2007).

[2] CHARPAN (Charged Particle Nanotech) is an integrated project of the European 6th Framework Program (FP6); www.charpan.com

[3] Elmar Platzgummer. Hans Loeschner, and Gerhard Gross, “Projection Mask-Less Patterning (PMLP) for Nanotechnology Applications”, accepted for publication in **J. Vac. Sci. Technol. B**, Nov/Dec 2008.

[4] IPhoS (Ion beam technology for Photonic Structures) as part of the cluster project PLATON (Processing Light-Advanced Technologies for Optical Nanostructures), funded by the Austrian Nano-Initiative: www.nanoinitiative.at

[5] BISNES (Bio-Inspired Self-assembled Nano-Enabled Surfaces) project of the 7th European Framework Programme (FP7).

[6] NILdirect-stamp project as part of the NanoImprint Lithography cluster project “NILaustria”, funded by the Austrian Nano-Initiative: www.nilaustria.at

[7] Holger Sailer, Institute for Microelectronics Stuttgart, Germany, private communication.

[8] Joerg Butschke, Mathias Irmscher, Holger Sailer, Lorenz Nedelmann, Hans Loeschner, and Elmar Platzgummer, “Mask patterning for the 22nm node using a proton multi-beam projection pattern generator”, SPIE Photomask BACUS 2008, Monterey, California, USA, Oct 6-10, 2008.

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Industry Briefs

More Customers like the Zeiss Mask Metrology System

By **Semiconductor International**

Carl Zeiss's (Jena, Germany) Photomask Registration and Overlay Metrology (PROVE) system is gaining market momentum. Developed by a team of 40 Zeiss engineers with support from Sematech (Austin, Texas), the PROVE system is considered a key building block for masks used in both 193 nm double patterning and extreme ultraviolet (EUV) lithography. The metrology tool uses diffraction-limited imaging optics operating at 193 nm. The at-wavelength optics provides flexible illumination for maximum contrast imaging and enables in-die pattern placement analysis on production patterns, according to Zeiss.

The first order came from NuFlare Technology Inc. (Tokyo), a major supplier of e-beam-based mask writers. NuFlare is convinced that the PROVE system enables a dramatic performance improvement of mask writing systems, according to Yasuaki Miura, president of NuFlare. The efforts to write masks for EUV and nanoimprint lithography, as well as the emergent double patterning and double exposure technologies, will be empowered. With NuFlare's selection of Zeiss, the system is on its way to becoming the de facto standard for calibration of the leading photomask writing tools. Both 193 nm double patterning and EUV lithography should significantly benefit from its accuracy.

Samsung Electronics was the second company to order the PROVE system from Carl Zeiss SMT, following to what the German company called a "breakthrough" from NuFlare. According to Oliver Kienzle, a member of the board at the Carl Zeiss SMT, considering the current market situation, these orders confirm that PROVE is an enabling technology for mask manufacturing at the 32 nm node and beyond.

Overlay Control goes to High-Order

By **Chin-Chou Kevin Huang, David Tien,** KLA-Tencor Corp.

More challenging overlay requirements are driving a trend to use high-order control knobs for production set-up of scanners. Historically, lithographers have achieved layer-to-layer alignment control by assuming that overlay varies linearly across the wafer and across the scanner field. Although more sophisticated "high-order" control knobs have been available during scanner setup and optimization, they were not typically used in production. It has only been in the recent past, driven by the aggressive shrink in overlay budgets and the added complexities brought forth by immersion lithography, that these high-order degrees of freedom have finally been adopted into the production control loop.

As lithography continues to advance beyond 40nm, overlay control will also need to continue to move forward with new and more sophisticated control strategies. High-order correction has been demonstrated as an effective approach in meeting current 40nm overlay control requirements. The source of variance analysis technique also provides a fast diagnostic methodology to troubleshoot and de-convolute complicated overlay control issues that could otherwise consume much more time and resources. Sample planning is another important factor that needs more consideration in the move to high-order control and can have significant repercussions to not only productivity, but also yield.

Finally, an effective high-order control strategy requires both grid and field control. Although high-order grid control has become widely accessible to users with the latest generation of scanners, high-order field control still requires more collaboration between the user and vendor. Specifically, on the scanner side, adjustment knobs for field control need to become more easily accessible. Moreover, on the metrology side, high-performance small targets that can be placed in-field to capture these in-field errors also need to be readily available in order to enable a production-worthy control solution. Looking ahead, one should be optimistic that these developments will continue to drive even more improved and effective high-order control strategies that can be readily integrated into production with compelling value creation for end users.

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About the BACUS Group

Founded in 1980 by a group of chrome blank users wanting a single voice to interact with suppliers, BACUS has grown to become the largest and most widely known forum for the exchange of technical information of interest to photomask and reticle makers. BACUS joined SPIE in January of 1991 to expand the exchange of information with mask makers around the world.

The group sponsors an informative monthly meeting and newsletter, BACUS News. The BACUS annual Photomask Technology Symposium covers photomask technology, photomask processes, lithography, materials and resists, phase shift masks, inspection and repair, metrology, and quality and manufacturing management.

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2009

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Photomask Japan

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